C-CORE Publication No. 90-22
pp 395-411

Ice Technology for Polar Operations

Proceedings of the Second International Conference on Ice Technology, held at Downing College, Cambridge University, UK, during 18-20 September 1990

Edited by: T.K.S. Murthy
J.G. Paren
W.M. Sackinger
P. Wadhams

Computational Mechanics Publications
Southampton Boston

92-01848/

C-CORE Publication No. 90-22

Deployment Strategy for Satellite Tracked Drifters to Support Iceberg Drift Forecasting

M. El-Tahan(*), B. Sanderson(**), S. Venkatesh(***)

(*) Centre for Cold Ocean Resources Engineering, Memorial University of Newfoundland, St. John's, Newfoundland, Canada A1B 3X5

(**) Department of Physics, Memorial University of Newfoundland, St. John's, Newfoundland, Canada A1B 3X5

(***) Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4

ABSTRACT

The objective of this work is to devise strategies for optimum deployment of Tiros satellite tracked Ocean Drifters (TOD's) in order to derive measurements of ocean currents for iceberg drift forecasting off the Canadian east coast. The mean velocity field of ocean currents and its standard deviation are determined from several data sources. The velocity field and its variability are used by a trajectory model to determine the probable movements of a TOD released in the study area.

A desirability index is defined to quantify the need for TOD measurements at a site in terms of the amount and type of human activity, the variability and knowledge of ocean currents, and the iceberg population density, and other considerations.

Based on the trajectory model, typical residence times for TOD's are about 2.5 months. For the area off Labrador, TOD releases should be within the Labrador current (between the 200 m and 1000 m isobaths) as far north as pack ice allows. Peak release times off Newfoundland should be in May to July in

order to coincide with peak iceberg numbers.

A prohibitive number (1000) of TOD's would be required to resolve eddy structure in the areas considered. However, a more reasonable number (20-100) of TOD's would adequately resolve much of the wind induced current variability.

1. INTRODUCTION

The driving force created by ocean currents is the primary factor influencing the drift of icebergs (El-Tahan *et al.*, 1983). The quality of iceberg drift prediction is directly dependent on the accuracy of current data. It is well known that currents off the Canadian east coast exhibit significant spatial and temporal variability (Petrie and Isenor, 1985). On the Grand Banks and Shelf the mean current is usually less than current standard deviation, and variable wind driven currents dominate the mean flow (de Young and Tang, 1989). The work of Garrett *et al.* (1985) indicates that the Lagrangian integral time scale for current residuals (after the mean current, tide and direct wind driven component are removed) is about 15 hours and the eddy space scale is about 31 km. It is, therefore, unreasonable to try to measure these residual eddy currents in a deterministic sense over the whole area of interest. However, wind driven currents and tidal currents have generally greater space scales and the tidal component can be modelled with some confidence (Petrie, *et al.*, 1987). Even if eddies cannot be resolved a real-time measurement program can be expected to yield measurements that will improve the localized (in time and space) estimates of current velocity beyond knowledge of the historical mean current.

The satellite-tracked Tiros Ocean Drifters (TOD's) are an economical means to provide near real time current measurements over an extended period of time. They have been successfully used by the International Ice Patrol (IIP) during the past few years as the primary method of deriving currents and also for temporarily updating the IIP current file, (Summy and Anderson, 1983). Because of the high cost of the drifters, one can count on having only a limited number available for this purpose. In view of the vast area covered by iceberg frequented waters and the variability of the currents within the area a strategy must be developed to optimize deployment of TOD's and to ensure cost-effective data collection.

Minimizing the risks to offshore human activity is the prime reason for providing an iceberg forecasting service. Therefore, the following four major factors are considered in development of the optimum TOD deployment strategy for a specified area: (1) the amount and type of human activity, (2)

the variability and knowledge of ocean currents, (3) the iceberg population density, (4) expected trajectory of TOD's relative to where they are needed.

In this paper a detailed discussion is provided of the four major factors mentioned above, with particular attention being given to the development of an ocean currents data base. The development of an ocean currents data base is essential to two of the four major factors: the understanding of the variability and the calculation of the expected trajectories. Based on these factors a Desirability Index that indicates the need for TOD data in a particular area is developed leading to the formulation of a deployment strategy.

2. OCEAN CURRENTS AND THEIR VARIABILITY

The need for TOD measurements at a locality is determined in part by (i) how well we know the local currents (ii) how variable these currents are. The currents and their variability must also be determined in order to estimate the probable long term trajectories of TOD's.

The total area of interest (42° to 60°N, 42° to 62°W) has been divided into 1° x 1° grid in the same manner as Petrie and Isenor (1983) and Petrie (1987). The following five sources of data are then used to obtain mean Lagrangian velocities in each grid. The underlined text indicates the name designated for each data source throughout the remainder of the text.

1. Bedford Institute of Oceanography <u>(BIO) drifter currents</u> (Petrie, 1987).

2. <u>BIO current meter data</u> collected from 1960 through 1986 at a variety of sites scattered over the Newfoundland Shelves and Slopes (Gregory, 1986).

3. <u>TOD current data</u> collected by IIP from experiments within the period 1983 through 1985 (Murphy and Anderson (1986)).

4. Currents derived from <u>ice drifters</u> deployed by BIO and tracked via the ARGOS system in the area between 52° to 60°N and covering the years 1984-1986. This data base includes 48 files, each containing a 30-day drifter track.

5. The comprehensive <u>IIP historical current</u> file which covers the area from 40° to 52°N and from 39°W to 57°W.

For all these data sets, except the IIP historical current file, the standard deviation of the current velocity is typically larger than the mean current (the IIP current file

has information only about the mean current). Petrie and Isenor (1985) find the ratio of mean currents to root mean square (rms) currents is 0.34 on the Grand Banks and somewhat larger in the Labrador Current. Clearly, such large variability greatly reduces the usefulness of mean currents as an estimator of local currents at any particular time. It also indicates the statistical significance of mean velocities in those grids where mean velocities are small and the number of measurements are few.

The five current data sets were averaged to obtain mean currents over the study area. Analysis of the five data sets indicated that the different data sets have systematic differences in the mean current speeds in a given common set of grids and that BIO Drifter Currents give the best estimates of mean Lagrangian surface layer currents. Thus, in Table 1 we introduce the velocity scaling factors for each data set so that grid speeds are normalized relative to BIO drifter currents. For example, BIO drifter currents are only 0.4 times as large as the IIP Historical Currents. It seems likely that IIP historical current data has high current speeds, particularly in the Labrador current, due to the inappropriate use of short drifter time series to "update" or perhaps "calibrate" the geostrophic current. In general, velocities that are averaged over short periods are expected to have higher speeds than velocities that are averaged over long periods (Venkatesh *et al.*, 1990).

The BIO drifter mean currents are larger than the BIO current meter mean currents by a factor of 1.9. However, the variance of the currents is the same in these two data sets. In very variable flow regimes it is possible for the Stokes transport to become comparable to the mean Eulerian current, and this might account for a large portion of the difference noted above. There is no way to test this conjecture with the available data.

A weighting of one data set relative to the other is also applied when compiling average velocities from the five data sources (Table 2). For our purposes, Lagrangian measurements are more relevant so BIO Drifter currents, TOD currents and Ice drifter currents receive a baseline weighting of 3. The BIO current meter data and IIP historical data are assigned weightings of 2 and 1 respectively. These baseline weightings are further modified according to the total number of days of measurements per grid as a ratio with that for BIO drifter currents. This results in weightings of 3 x 0.028 = 0.084 for TOD currents and 3 x 0.12 = 0.36 for ice drifters. The density of BIO current meter data is similar to the density of BIO drifter data.

Scaling and weighting factors for the standard deviation of currents were arrived at in a similar manner to those for the mean currents and are also presented in Tables 1 and 2. A plot of the average current vectors in each grid, obtained by applying the above factors to the five data sets, is presented in Figure 1.

The current follows bottom contours and the presence of the Labrador current is clearly evident. It consists of an inshore branch along the coast of Newfoundland, the main current through Flemish Pass and along the edge of the Grand Banks, and a component that branches eastward around the northern end of Flemish Cap. Typically, the average velocity field underestimates the Labrador Current speed, because the Labrador current has a width of 50 km (less than the grid dimensions) and horizontal excursions of about 60 km (Petrie and Isenor, 1985). On the Grand Banks the mean current is weak, typically 0.05m/s, and the standard deviation is typically three times as large, ±0.15m/s. Throughout most of the study area the standard deviation of velocity is greater than the mean velocity by a factor of about two or three. Even in those grids where the mean current is large, in the Labrador current for example, the standard deviation of velocity is still usually of a similar magnitude to the mean.

3. THE DESIRABILITY INDEX

The following parameters are considered important for determining the requirement for measurements of the Lagrangian velocity field for the optimum deployment of TOD's.

3.1 The Iceberg Density Parameter D_{IIj}

This parameter is the number of icebergs observed in each grid over the spring (or summer) months and averaged over the years 1960-84. Figure 2 presents parameter values for summer (May, June, July). Iceberg density data were obtained from the IIP 1960-84 data base.

The general geographic distribution of icebergs in spring is very similar to that of summer. The major difference is that there are more icebergs in summer than in spring, although they are confined to almost the same area. However, there is large variation within each season.

3.2 The Human Density Parameter D_{HIj}

There are many types of human activity in the study area. Drilling operations have minimal manouverability and need to maintain a fixed position. They have, therefore, a paramount interest in the predicted motion of icebergs. It will be assumed therefore that the human density parameter depends only upon drilling operations, and not upon other forms of human

activity.

The human density parameter at a given location is proportional to the drilling activity in the immediate vicinity and downstream. Figure 3 shows positions of all drilling operations in the region of interest for the period 1973-1987. The parameter D_{Hij} will be calculated using the following algorithm. Starting from a value of 0, a value of 4 will be added to D_{Hij} if there is any drilling (one or more drilling rigs) in the (i,j) grid (i,j represent grid coordinates) D_{Hij} will be increased by 2 if there is any drilling immediately downstream of (i,j), by 1 if there is any drilling two grids downstream from (i,j) or in a neighbouring grid that is across stream from (i,j).

For the present study the D_{Hij} have been calculated based on all the sites occupied by drilling operations over the years 1973-1987. In any given year it is likely that only a small subset of these sites actually are occupied and for operational purposes, D_{Hij} should be changed accordingly.

3.3 The Current Variability About the Mean Velocity Parameter D_{Vij}

In a grid where the standard deviation of the velocity is large, it is necessary to make frequent measurements. From the standard deviation σ_u and σ_v of the x and y components of velocity, we define the following desirability of measurement parameter for the (i,j) grid.

$$D_{Vij} = \sqrt{\sigma_{uij}^2 + \sigma_{vij}^2} \qquad (1)$$

The parameter D_{Vij} is related to the uncertainties of velocity and therefore the uncertainty of predicted iceberg trajectories. The values of D_{Vij}, shown in Figure 4 vary from grid to grid but not in a random fashion. Symbols plotted in each grid indicate that there are distinct regions where D_{Vij} is large and others where it is small. Most of the drilling operations are not in areas with large values of D_{Vij}.

3.4 Combining the Parameters

The ultimate need for TOD measurements in a grid, the total desirability index, D_{Tij}, is defined as:

$$D_{Tij} = D_{Iij}\, D_{Hij}\, D_{Vij}, \qquad (2)$$

in keeping with the fact that measurements are needed only when all three parameters are non-zero.

Values of D_{Tij} are plotted in Figure 5 for the summer seasons. The distribution of TOD's should be similar to the

distribution of D_T in order to provide measurements that are most likely to aid in the forecast of trajectories of icebergs that could threaten drilling operations. The actual number of TOD's deployed in a given grid will be dependent on the total number available.

The areas of interest are aligned along the direction of the mean currents. This is fortunate because it means that TOD's released properly at the north can be expected to provide useful information as they drift southwards. The areas of interest seem to fall into two groups, the northern group (grids 1 to 20 in Figure 6) are along the Labrador Shelf in an area that is affected by the Labrador current and the southern group (grids 21 to 98 in Figure 6) are along the eastern side of the Grand Banks and Flemish Pass area.

Grids that have the largest values of D_T are found in the northern group. This is because of the generally large number of icebergs and large variability of the currents in the area. However, there are more grids in the southern group that have non zero values of D_T and therefore need to be monitored with TOD's.

The northern group is a narrow band of grids that follows the coast. The southern group is broader in the cross-stream direction. Again, this is fortunate because the variability of a TOD's cross-stream position will increase as it travels downstream from a release point to the north. This increases the likelihood that TOD's released in the northern group might eventually provide useful measurements in the southern group.

4. THE TRAJECTORY MODEL

In general we can ensure that a TOD will produce useful data by releasing it in a grid where D_T is non zero. To determine whether or not a TOD will provide useful data at some later time we need to know where it might go. We calculate the envelope of probable trajectories for a TOD as it is advected by the mean field and its position is made uncertain by the velocity fluctuations about the local mean velocity. The advective velocity within the (i,j) grid will be computed by linear interpolation of the mean velocity field of (i,j) and the surrounding grids. The uncertainty of the trajectory will be computed using standard methods, describing dispersion by continuous movements in a stationary homogeneous field of turbulence (Taylor 1921). For times that are large compared to the Lagrangian integral time scale, τ, (taken to be 15 hours) the standard deviation of position is the following function of the local standard deviation of velocity:

$$\sigma_x = \sigma_u \sqrt{2\tau t} \tag{3a}$$

$$\sigma_y = \sigma_v \sqrt{2\tau t} \tag{3b}$$

For our data σ_u varies very little as the TOD progresses along its track for a period equal to τ, so the implicit assumption of quasi-stationarity is good.

The trajectory model has been run for TOD's starting at the centre of each grid in which the value of D_T is nonzero. In general the uncertainty ellipses are oriented with the major axes aligned in the north-south direction, consistent with the greater variability of currents in that direction. In general the mean current has a larger north-south component than east-west component.

5. THE DEPLOYMENT STRATEGY

In this section, information on the desirability index, the trajectory model and the number of TOD's available for deployment will be combined to come up with a deployment strategy. Parameters such as average density and separation of TOD's (within the area requiring measurements) will be given as a function of the number of TOD's available for release.

5.1 Implications of D_T and the Trajectory Model for a Deployment Strategy

In earlier discussions, based on the Desirability Index, the areas that needed TOD coverage were defined. The total area that needs TOD coverage is 48 grids or approximately A_G = 420,000 km^2. Thus even if n=100 TOD's were to be kept in the study area at all times, the average density of TOD's would be only one per 4,200 km^2 .

Thus, the average separation between TOD's D is given by

$$D = \sqrt{A_G/n} \tag{4}$$

and for the above values of A_G and n we find D = 65 km. This coverage is too coarse to resolve the eddies. Bathymetric features have horizontal scales greater than 65 km over much of the study area. Wind stress and tidal forcing will be strongly correlated at scales of 65 km. Further the external Rossby radius is of the order of 400 km or greater. Therefore D=65 km is sufficient for resolving wind driven currents (Ekman currents) and the barotropic features of the tidal currents. It is likely that in regions of steep bathymetry, such as the shelf break, that there will be poorly resolved structures in the currents.

Trajectories of TODs released from each of the grids with nonzero D_T have been examined in greater detail elsewhere (see Fenco Newfoundland Ltd., 1987). In order to get good coverage of the southern group of grids (during ice free periods) and maximize the amount of useful data per TOD, releases should primarily be made in grids 21, 22, 23, 25 and 26 (Figure 6). Of course, if by chance TOD's do not cover some area then deployments must be made in that area to cover the immediate need. Figure 7 shows sample trajectories for releases from two different grid boxes. Trajectory uncertainty ellipses are drawn after two weeks and then at monthly intervals for four months subsequent to release. The principal axes of uncertainty ellipses mark plus and minus one standard deviation calculated using Eqs. 3a,b. Thus there is a 68% probability that the TOD will be within this ellipse.

5.2 Consideration of Sea Ice

The sea ice extends down the coast of Labrador and east of Newfoundland in the spring (Markham 1980). In March and April the ice extends south of 45°N, but the usual median position of the ice edge is north of 48°N. By late April the sea ice has usually receded from most of the area occupied by the southern group. However, the sea ice does not usually start to clear from the northern group until late May or early June. Since TOD's cannot operate in pack ice it is appropriate to consider a shortened deployment season for the northern group, consisting of the months June-September. The deployment season will still be March-September for the southern group since we expect that a large portion of the southern group will not be ice-covered in this period. It is therefore suggested that about 35% of the TOD's available be deployed in the northern group and 65% in the southern group. It should be noted that some portion of the TOD's released in the northern group will also give useful data for the southern group.

5.3 A Recommended Deployment Strategy for the Southern Group

Release sites for the southern group should be in the vicinity of Grids 21, 22, 23, 24 and 26 or as close as ice cover allows. Note that by only having release sites at the upstream end of each group the residence time is maximized. Frequent trips will be required to redeploy TOD's that drift out of the study area. If T_D is the interval between releases, the number of TOD's released at each dropoff is

$$N_R = NT_D / T_{season} \qquad (5)$$

where N is the total number of TOD's available and T_{season} is a time period (over a season) for which TOD coverage is required. The area, A_D , over which these N_R TOD's are initially dropped off should be chosen to give a separation between neighbouring TOD's that is similar to that given by (4). The deployment

scheme for the southern group should be modified by making the number of TOD's released at any particular time proportional to the iceberg density at that time divided by the average iceberg density over the months March through September (see scale factor in Table 3). Thus for releases in the southern group N_R should be multiplied by the scale factor (Table 3) of the particular month in which the release is taking place.

It is of interest to consider the coverage that can be expected for an area that is a subset of the total area of the southern group. Let us choose an area with half the linear dimensions and therefore one quarter the square of the dimensions but of a similar shape. Therefore the residence time could be expected to be about T_R = 1.25 months, which is half that in Table 4 and the area is A_0 = 61,750 km^2 (= 250 km x 250 km). Given 100 TOD's to be released in the iceberg season (and therefore N = 65 of these will be released in the Southern Group) then the average distance between TOD's can be shown to be about 73 km and the number of TOD's in the area of interest at any one time would be $n = N\ T_R\ /T_{season} = 12$. Still we would not be able to resolve the eddy field throughout the iceberg season.

Another point of interest is that sometimes it seems desirable to place a TOD next to an iceberg. Even given that the TOD is drogued so that it moves through the water in the same way as an iceberg, it will still "diffuse" away from the iceberg. Given the velocity statistics described earlier and Garrett et al's (1985) integral time scale, equation (4) shows that the expected separation would be 10 km after ten hours; 18 km after 20 hours; 35 km after 50 hours. So, after two days the residual eddies moving the TOD would probably become decoupled from those moving the iceberg.

6. CONCLUSIONS

1. The northern group TOD's should be released within the Labrador Current as far to the north as ice conditions allow.

2. TOD's released in the Labrador Current at the northern end of the northern group would give adequate coverage of that group and result in an average residence time of about 2.5 months. Releases in other areas would reduce the residence time.

3. It would be very expensive to resolve the eddy current structure using TOD's.

4. Since much of the northern group is ice-covered at the beginning of the iceberg season, we suggest that 35% of the TOD's be deployed in the northern group and 65% in the southern

group.

5. Values of parameters related to the coverage expected with various numbers of TOD's are summarized in Table 4.

6. A release beside a particular iceberg is only likely to provide measurements of velocity relative to the mean, correlated to the motion of the icebergs for periods of about one to two days. After this period of time the TOD and iceberg are likely to be separated by distances larger than the eddy scales.

7. Parameters such as D_E change from year to year. Therefore the specific examples used to illustrate the deployment strategy are not necessarily applicable to any particular year, or indeed any year at all. We have, however, developed a robust method of arriving at a deployment agenda.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Donald Murphy of the International Ice Patrol and Dr. Brian Petrie of the Bedford Institute of Oceanography for their assistance during the course of this project. Financial support for the project was provided by the Canadian Federal Panel on Energy Research and Development.

REFERENCES

El-Tahan, M., El-Tahan, H. and Venkatesh, S., 1983, "Forecast of Iceberg Ensembles Drift", Offshore Technology Conference, Houston, Texas, OTC Paper, No. 4460, May 2-5.

Fenco Newfoundland Ltd., 1987, "Optimum Deployment of TOD's (Tiros Ocean Drifters) to Derive Ocean Currents for Iceberg Drift Forecasting", Report submitted to Meteorological Services Research Branch, Atmospheric Environment Service (AES), Downsview, Ontario.

Garrett, C., Middleton, J., Hazen, M., Majaess, F., 1985, "Tidal Currents and Eddy Statistics from Iceberg Trajectories off Labrador", Science 227, pp. 1333-1335.

Gregory, D., 1986, "Bedford Institute of Oceanography Inventory of Current Meter Data". Internal Report, Bedford Institute of Oceanography, Dartmouth, N.S., 262pp.

Markham, W.E., 1980 Ice Atlas, "Eastern Canadian Sea-board", Environment Canada, Atmospheric Environment Service, Toronto, Ont. 96 pp.

Morgan, C.W., 1974, "Long-term Trends in the Iceberg Threat in the Northwest Atlantic". In: Report of the International Ice Patrol Service in the North Atlantic Ocean. U.S. Coast Guard, Washington, DC, Bulletin 57, CG-188-29, pp. 15-26.

Murphy, D.L., and Anderson, I., 1986, "An Evaluation of the International Ice Patrol Drift Model", Proceedings of the Canadian East Coast Workshop on Sea Ice, January 7-9, 1986. Bedford Institute of Oceanography, Atlantic Oceanographic Laboratory, Dartmouth, N.S., pp. 387-409.

Petrie, B. and Isenor, A., 1983, "An Analysis of Satellite Tracked Drifter Observations Collected in the Grand Banks Region", Can. Tech. Rep. Hydrogr. Ocean Sci., 39, Bedford Institute of Oceanography, Dartmouth, N.S.: 64 pp.

Petrie, B. and Isenor, A., 1985, "Near-Surface Circulation and Exchange in the Newfoundland Grand Banks", Atmosphere-Ocean 23: 09-227.

Petrie, B., 1987, "Personal Communications and Correspondence".

Petrie, B., Lark, K., and DeMargerie, S., 1987, "Tides on the Newfoundland Grand Banks, Atmosphere-Ocean, 25: No. 1: 10-21.

Summy, A.D. and Anderson, I., 1983, "Operational Uses of Tiros Oceanographic Drifters by the International Ice Patrol (1978-1982)", Proceedings of the Symposium on Buoy Technology, pp. 246-250, New Orleans (Marine Technology Society, Washington, D.C.).

Taylor, G.I., 1921, "Diffusion by Continuous Movements", Proc. London Math. Soc., A20: 196-211.

Venkatesh, S., Sanderson, B. and El-Tahan, M., 1990, "Optimum Deployment of Satellite-Tracked Drifters to Support Iceberg Drift Forecasting", Journal of Cold Regions Science and Technology, V. 18.

de Young, B. and Tang, C., 1989, "Storm Forced Baroclinic Near-Inertial Currents on the Grand Bank", submitted to Journal of Physical Oceanography.

Table 1 Scaling factors for Velocity and Standard Deviation of the Five Data Sets

DATA SET	SCALING FACTOR FOR VELOCITY	SCALING FACTOR FOR STANDARD DEVIATION
Petrie (BIO mean Drogue Data)	1	1
TOD 83-85 Currents (Special Edition)	1	1
Labrador Ice Transmitters	0.65	1
BIO Current Meter	1.9	1
IIP Current File	0.4	Not used

Table 2 Weighting Factors for the Different Data Sets

DATA SET	WEIGHTING FACTOR FOR VELOCITY	WEIGHTING FACTOR FOR STANDARD DEVIATION
Petrie (BIO Mean Drogue Data	3	3
TOD 83-85 (Special Edition)	3 x 0.028	3 x 0.028
Labrador ice Transmitters	3 x 0.12	3 x 0.12
BIO Current Meter	2	2
IIP Current File	1	Not used

Table 3 Monthly Iceberg Densities South of 48°N and a Scale Factor for the Number of Drogues Released in the Southern Group during Different Months in The Iceberg Season (adapted from Morgan, 1976).

MONTH	MONTHLY AVERAGE NUMBER OF ICEBERGS SOUTH OF 48°N	SCALE FACTOR FOR NUMBER OF TOD'S RELEASED, IN THE SOUTHERN GROUP DURING EACH MONTH
January	2	-
February	7	-
March	37	0.76
April	93	1.90
May	120	2.45
June	64	1.31
July	20	0.41
August	6	0.12
September	3	0.06
October	2	-
November	2	-
December	1	-

Table 4 TOD Release and Coverage Parameters if a Total of 1000, 200, 100, 20 TOD's are available for deployment.

	Northern Group	Southern Group
Length of deployment season, T_{season} (months)	4	7
Total Area of Group, A_{Group} (km^2)	176,000	247,000
Residence Time, T_R (Months)	2.5	2.5
Average Speed, V_m (km/day)	15	9
Number of TOD's to be deployed through the season, N	350, 70, 35, 7	650, 130, 65, 13
Number of TOD's in study area at any one time, n	220, 44, 22, 4	230, 46, 23, 5
Average separation between TOD's D (km) (Eq. 4)	28, 63, 90, 200	33, 73, 104, 220
Drop off interval, T_D (weeks)	2	2
Number of TOD's released at each drop off (Eq. 5) N_R	44, 9, 4, 1	46, 9, 5, 1
Drop off area A_D (km^2)	35,200	49,400
Expected drift between deployments = $7V_m T_D$ (km)	210	126

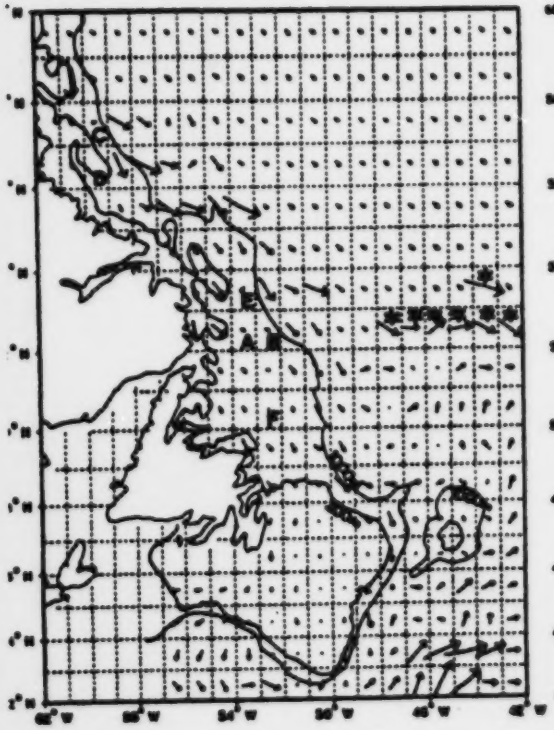

Figure 1 A velocity vector plot of the combined current data, for the area of interest divided into one degree squares. The Belle Isle Bank region is shaded. The asterisked grids have currents derived from only one ice drift trajectory. Currents in grids A and B are derived by applying a spatial filter. Currents in grids C, D, E and F have suspect directions.

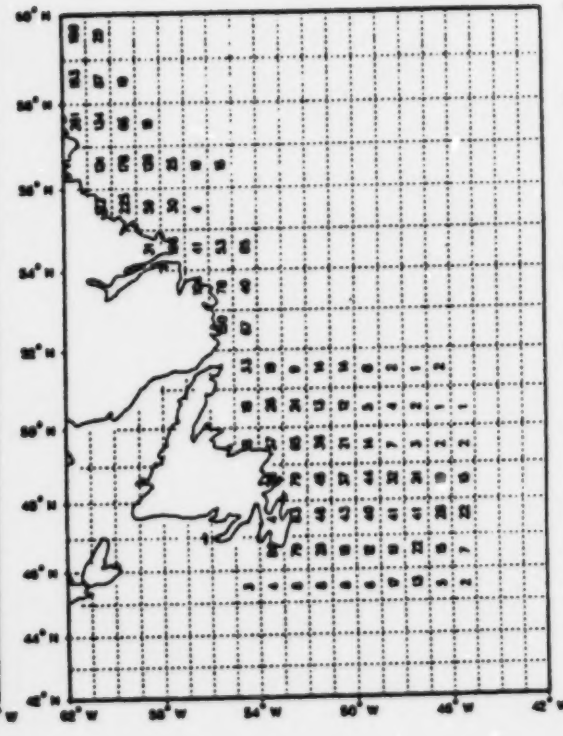

Figure 2 Average number of icebergs observed in each grid for the summer months over the period 1960 -84, $D_{I\,i\,j}$.

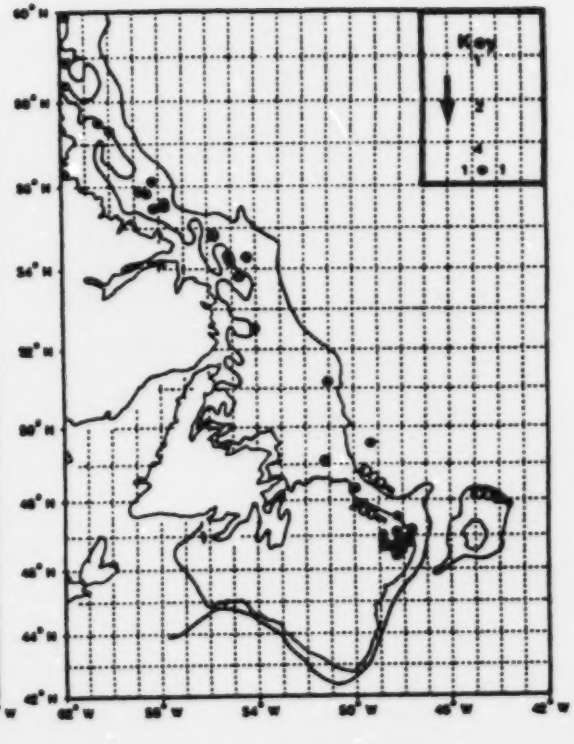

Figure 3 Wellsites in offshore Newfoundland and Labrador 1973-1987, and a key for the algorithm to calculate $D_{H\,i\,j}$.

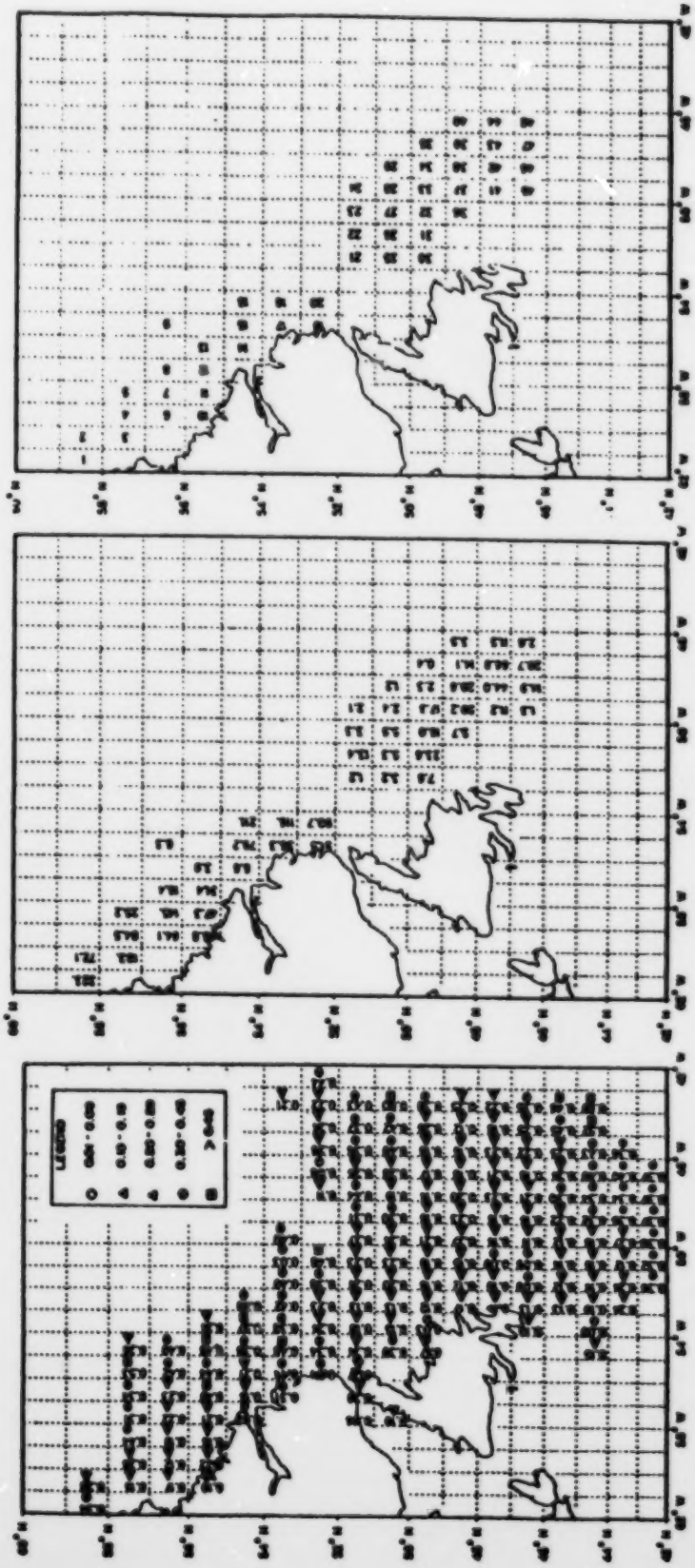

Figure 4 The variability about the mean velocity (ms^{-1}) parameter $D_{V1,j}$.

Figure 5 Total desirability index for spring, $D_{T1,j}$.

Figure 6 The numbering system for grids in which D_T is nonzero.

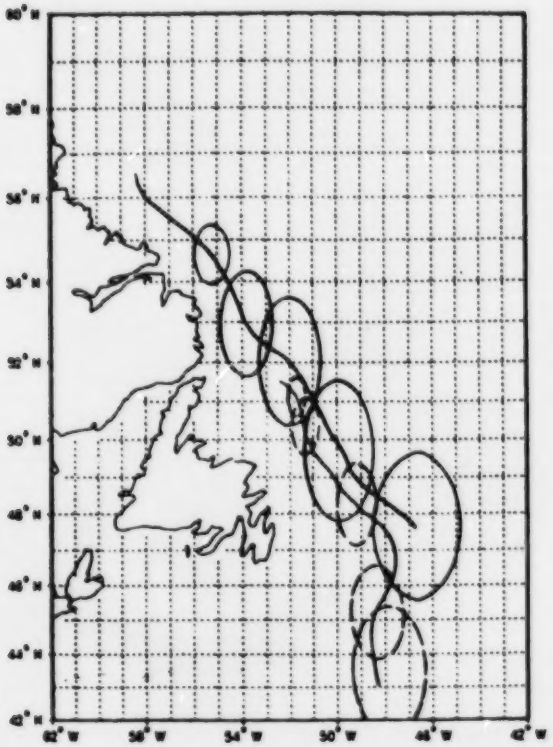

Figure 7 Trajectory and uncertainty ellipses for a release from grid numbers 7 and 21, are plotted with solid and broken lines, respectively.